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Report

The Efficacy of a Mattress Type Sleep Measuring Device in Analyzing Sleep in Healthy University Students: Comparison with Actigraphy

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Sleep disturbance relates to various disorders and is a significant public health issue. Evaluation of sleep quality is necessary to analyze and improve sleep quality. Polysomnography (PSG) is an efficient method for sleep analysis. However, complicated systems are required for the analysis. Also, PSG can be stressful for participants and is, therefore, not suitable for long term sleep monitoring. Sleepscan is a non-invasive mattress type sleep measuring device developed by TANITA. Sleepscan measures the participant's heart rate, respiration, and body movement during sleep, and evaluates sleep quality objectively. We measured the sleep quality of healthy university students with Sleepscan and a widely-used sleep measuring device, actigraph. We also discussed the efficacy of using Sleepscan daily. Sleepscan detected longer sleep latency and shorter awake episodes during sleep than actigraph. Although these devices showed quite different results for some sleep variables, the sleep score recorded by Sleepscan and sleep efficiency by actigraph correlates well. Since sleep efficiency is used as a representative index for comprehensive sleep quality in actigraphy, the sleep score by Sleepscan can be an alternative index used to evaluate sleep quality objectively. Sleepscan can also analyze the depth of sleep. The deep sleep variables recorded by Sleepscan did not correlate with the sleep variables by actigraph, suggesting that these variables may represent aspects of sleep quality that cannot be detected by actigraphy. Sleepscan may be useful in analyzing sleep quality objectively more comprehensively over a long period.

Key words sleep quality, non-invasive sleep monitoring, sleepscan, actigraphy

INTRODUCTION

Almost one out of five Japanese complain about their sleep.[1] Sleep disturbance leads not only to sleep disorders such as insomnia but also to various physical and mental disorders. In addition to the duration of sleep, the quality of sleep has been recognized as an important factor. Epidemiological studies have indicated that chronic low sleep quality correlates with various disorders such as obesity, metabolic syndrome, diabetes, cardiovascular diseases, and depression.[2–4] Maintaining sleep quality might reduce the risk of these diseases and improve patient's quality of life. Preventing sleep disturbances is an important issue for public health.

Efficient monitoring of daily sleep quality in an objective manner is necessary to detect early signs of sleep disturbance and improve sleep quality. Polysomnography (PSG) is the gold standard for objective sleep quality analysis.[5] PSG measures electroencephalography, respiration, electromyogram, electrocardiogram, a saturation of percutaneous oxygen, and body movement during sleep. According to these parameters, the PSG analyzes the sleep status of the participant and divides their sleep duration into several stages. These stages are awake, rapid eye movement (REM) sleep and non-REM (NREM) sleep. NREM sleep is further divided into four stages, stage 1 to stage 4. Stage 3 and 4 of NREM sleep are usually evaluated as deep slow-wave sleep. The amount of deep sleep is considered to be an indicator of good sleep quality. PSG could provide detailed information about sleep quality. However, measurement with PSG is not suitable for the analysis of sleep conditions in daily life. The participant has to be installed with lots of sensors and spend a night in the hospital or an experimental room. Analysis with PSG is stressful for participants, and continuous long term measurement is not a viable option. Alternative methods for long term monitoring of objective sleep in daily life are required.

Simple devices that analyze sleep have been developed and are widely used in epidemiological studies. Actigraph is a wristwatch type device that measures body movement by accelerometers and is one of the most popular devices for objective sleep analysis.[6–8] Body movement during sleep indicates that the body is physiologically awake even if the participant is not aware they are. Frequent and prolonged awake episodes during sleep suggest poor sleep quality. Actigraphy could evaluate objective sleep quality by measuring various sleep variables such as sleep latency, wake after sleep onset (WASO), and sleep efficiency. Since the analysis with actigraph is not as stressful for the participants, actigraphy is useful for long term sleep analysis in daily life. However, actigraphy can not analyze the depth of sleep. This is a limitation of analyzing sleep using actigraph.

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Sleepscan is a different type of sleep measuring device developed by TANITA. Sleepscan is a mattress type device that is put underneath the mattress of a bed. Since a participant does not physically contact the device, there is no risk of affecting their health. Sleepscan detects heart rate, respiration, and body movement during sleep by using a water pressure sensor installed in the device.[9,10] It can analyze sleep variables as well as actigraphy. Furthermore, Sleepscan can analyze the depth of sleep. A comparison with PSG revealed that Sleepscan could distinguish sleep from awake with a sensitivity of 97.4%, a specificity of 38.0%, and an accuracy of 92.5% in healthy volunteers.[10] Although these indices show lower values in the analysis of patients with obstructive sleep apnea,[10] Sleepscan can be a useful tool for objective sleep analysis.[11] In this study, we evaluated the efficacy of Sleepscan in daily life by comparing the sleep analysis from Sleepscan with actigraphy. We measured the sleep quality of healthy university students with Sleepscan and actigraph, analyzed the difference in the sleep analysis of these devices, and discussed using Sleepscan as a sleep measuring device in daily life.

MATERIALS AND METHODS

Participants and Procedure The participants consisted of 29 healthy university students aged between 20 and 24 years old (13 males and 16 females). They were recruited by an announcement posted on bulletin boards at the campus of Josai International University. All volunteered to participate in the study. The participants were required to be healthy; i.e., those who were taking any medication or in subjectively poor physical or mental conditions were excluded. All participants fulfilled the entry criteria. Although smoking was not included in the entry/exclusion criteria, there were no smokers included. Before the experiment began, an outline of the study was explained to them, and they signed an informed consent form.

The participants were instructed to wear an ActiSleepMonitor (ASM; Actigraph, Pensacola, FL, USA) on the wrist of their nondominant hand and to place the Sleepscan SL-501 (Tanita, Tokyo, Japan) under their mattress for 7 d. They were instructed to maintain their usual lifestyle and sleep habits in their homes during the experiment.

Procedures were conducted from January to October 2011. All procedures were approved by the Institutional Research Ethics Committee of Josai International University (approval number: 22) and were performed following the ethical standards of the 1964 Declaration of Helsinki and its amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

Sleep Analysis by Actigraph and Mattress Type Sleep Measuring Device Objective sleep was recorded using ASM and Sleepscan. The ASM is a wristwatch type actigraph. The ASM recorded the participant's body movement, and the collected data were analyzed by the data analysis software for ASM, ActiLife6 (Actigraph, Persacola, FL, USA). This software uses the standard sleep scoring algorithms developed and validated by Cole and colleagues.[12] The Sleepscan recorded the participant's respiration and pulse as well as their body movements and analyzed sleep status using the data analysis software provided by TANITA. Both devices measured the following sleep variables. Sleep latency: duration from the time of going to bed to the time when they fell asleep, wake after sleep onset (WASO): the total amount of time that is scored as awake after sleep onset, the Total sleep time (TST): the total amount of time that is scored as asleep, i.e., sleep latency and WASO are subtracted from the total time in bed as well as Sleep efficiency: the ratio of TST to the total time in bed. Also, Sleepscan analyzes the depth of sleep and measures the amount of deep sleep. Sleepscan also provides a sleep score that is calculated by TANITA's analysis software.[13]

In the analysis of sleep variables, the aggregation of data over several nights is routinely done to minimize the intra-individual inter-day fluctuation of the sleep variables.[14] We used the mean value of each measure during the session as the representative value of each participant. Some participants sometimes forgot to use the ASM or Sleepscan, and data were missed. If the successfully obtained data were less than 3 d, all of that participant's data were excluded from the analysis. As a result, we excluded the data of three participants (1 female, 2 males).

Statistical Analysis Linear correlation between two factors was analyzed using Pearson's correlation analysis. The significance level was set as $p < 0.05$. All statistical analyses were performed with R (The R Foundation for Statistical Computing, Vienna, Austria).

RESULTS AND DISCUSSION

Figure 1 shows representative sleep charts obtained from the ASM and Sleepscan. The ASM estimates sleep status as two stages, awake or asleep, while Sleepscan estimates the status in more detail, awake and three sleep stages, light to deep sleep. Figure 1A shows several long deep sleep episodes and a few awake episodes during the first half of the sleep. On the other hand, Fig. 1B shows short deep sleep and lots of awake episodes that suggest fragmented sleep. Sleep efficiency by ASM and the sleep score by Sleepscan of these periods of sleep were 89% and 73 points (Fig. 1A) and 66% and 45 points (Fig. 1B), respectively. These variables are used as a comprehensive index of sleep quality, with sleep efficiency lower than 85% suggesting poor sleep quality. Figures 1A and 1B are representative of good sleep and poor sleep, respectively.

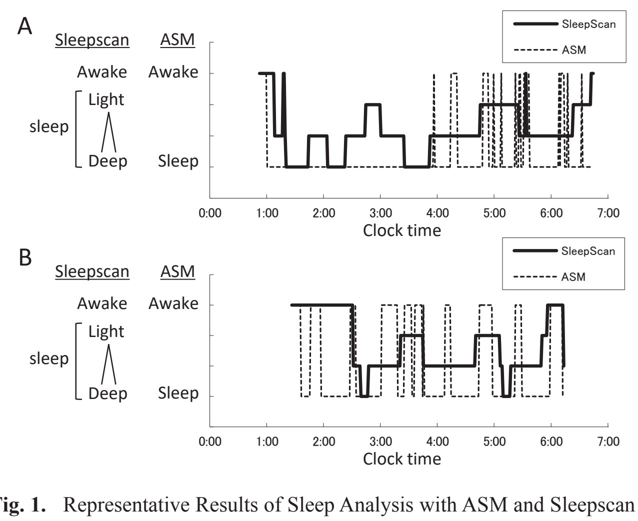

Fig. 1. Representative Results of Sleep Analysis with ASM and Sleepscan

Two representative sleep charts were shown. The solid line and dotted line represent the results from the Sleepscan and ASM, respectively. The ASM estimates the status as awake or asleep. The Sleepscan estimates the status as awake, light-, intermediate-, or deep-sleep. Start (going to bed) time and finished (wake up) time were 0:52 and 6:43 in A, and 1:26 and 6:13 in B, respectively.

Table 1. Sleep Variables Obtained from the ASM and Sleepscan

	Males	(n = 11)	Females	(n = 15)
	ASM	Sleepscan	ASM	Sleepscan
TST (min)	314.8 (289.1, 333.0)	346.1 (284.8, 432.8)	331.5 (293.1, 367.0)	363.6 (266.9, 398)
Sleep latency (min)	6.9 (6.1, 9.2)	13.6 (11.3, 20.1)	6.5 (5.5, 7.9)	13.6 (10.8, 24.0)
WASO (min)	69.7 (64.6, 78.9)	4.9 (1.0, 13.1)	57.1 (39.5, 78.0)	1.0 (0, 10.5)
Number of awakenings (times)	22.4 (16.7, 26.8)	0.3 (0.1, 2.0)	16.9 (14.1, 23.1)	0.3 (0, 0.6)
Sleep efficiency (%)	79.6 (76.1, 82.2)	96.3 (94.9, 98.3)	85.5 (78.6, 88.3)	98.3 (95.3, 98.9)
Deep sleep (min)	NA	109.9 (99.8, 125.0)	NA	116.3 (68.1, 138.6)
Sleep period (min)	NA	97.3 (90.3, 108.8)	NA	91.9 (75.4, 98.3)
Sleep score (points)	NA	60.4 (50.7, 70.9)	NA	70.9 (52.0, 78.0)

Median (25th and 75th percentiles) values are shown.
NA; not applicable.

Table 1 shows a summary of sleep variables obtained from the ASM and Sleepscan in the male and female participants. The median of sleep efficiency by ASM is 79.6% and 85.5%, suggesting that the participants were slightly poor sleepers as a population. Since no remarkable difference was observed between males and females, the following analyses were conducted with combined data from both sexes.

Figures 2 and 3 analyzed the correlation of sleep variables between both devices. TST showed a significant correlation between the ASM and Sleepscan (r = 0.633), while the other variables show a nonsignificant weak correlation (Fig. 2). Bland-Altman plots indicate that Sleepscan tended to obtain longer sleep latency, shorter WASO, and higher sleep efficiency than the ASM (Fig. 3). Sleepscan is comparable to the ASM for the analysis of TST, but not for the other sleep variables.

These results are inconsistent with a previous study that reported a strong correlation between Sleepscan and actigraphy in TST, WASO and sleep efficiency.[15] This inconsistency may be caused by the different demographics of the participants. Participants in the present study were young and displayed poorer sleep quality overall. Since the accuracy of the sleep analysis by Sleepscan is diminished in the analysis of patients with sleep apnea,[10] we speculate that poor sleep quality of the participants in the present study might have disrupted the correlation of some sleep variables. Since these studies were analyzed with small number of participants, further analysis with a larger number of participants is necessary to clarify the precise correlation between devices and these sleep variables.

The differences in sleep variables between the ASM and Sleepscan (Table 1, Fig. 2 and 3) should be due to the difference in the sleep/awake estimation of these devices. As shown in the sleep charts in Fig. 1, when Sleepscan detected deep sleep, ASM also detected sleep. However, when Sleepscan detected lighter sleep, ASM detected these as awakenings. There were large inconsistencies in the sleep/awake estimation during light sleep. This difference might cause shorter WASO and higher sleep efficiency by Sleepscan.

Sleep latency and WASO are important when assessing sleep complaints,[1] and accurate estimation of these variables is important for sleep analysis. Previous studies revealed that actigraphy provides high sensitivity to detect sleep, but poor specificity to detect awakeness in various conditions.[7,16–19] Actigraphy is useful in the estimation of TST, WASO, and sleep efficiency, but its ability to estimate sleep latency is limited.[16] Sleep analysis with actigraphy tends to underestimate sleep latency.[17,19] Since actigraphy evaluates the sleep/awake status by body movement, actigraphy may estimate a motionless period as sleep even if the participant is awake.[6,7] For

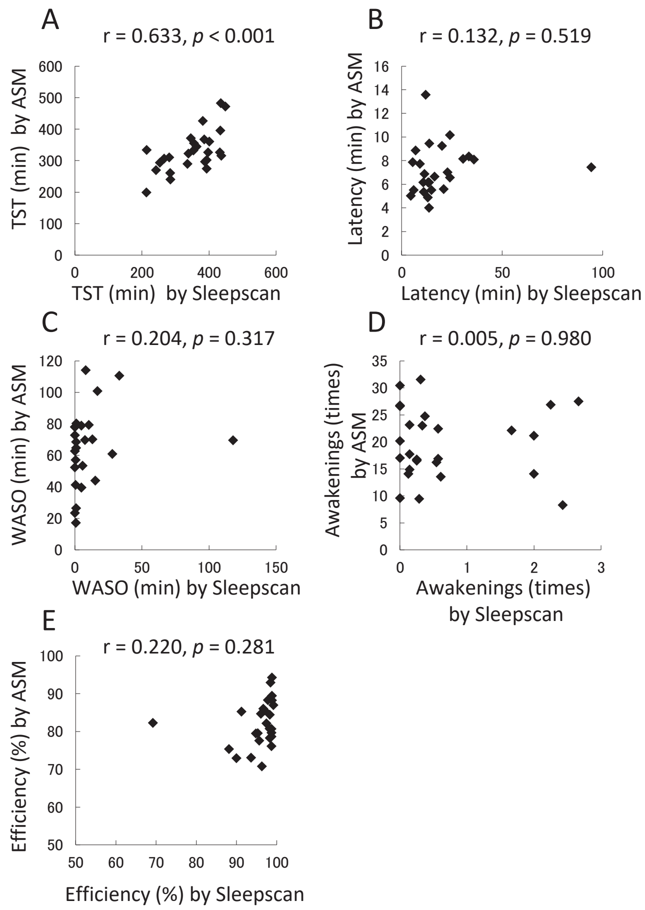

Fig. 2. Correlation between the Sleep Variables Obtained from the ASM and Sleepscan

TST (A), sleep latency (B), WASO (C), number of awakenings (D), and sleep efficiency (E) by the ASM and Sleepscan were plotted. Each plot represents the data from each participant.

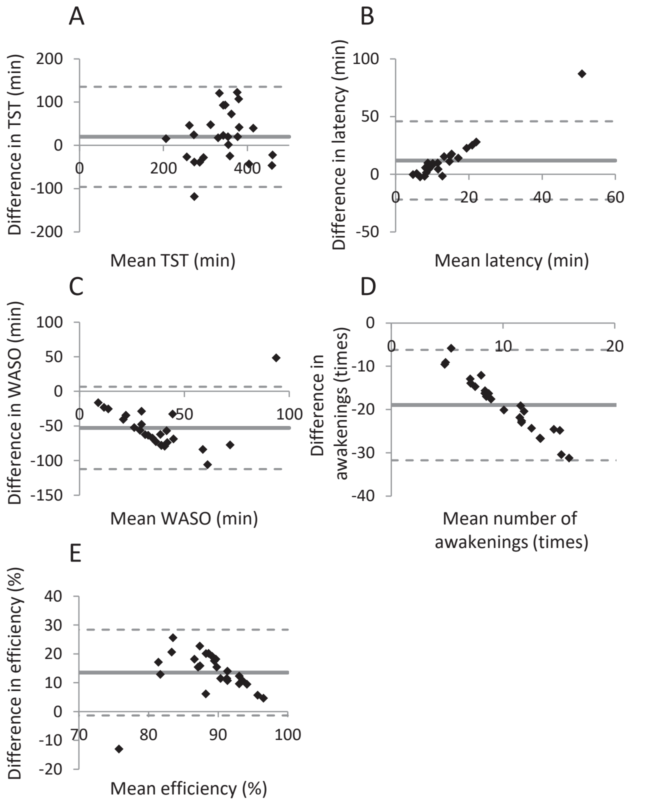

Fig. 3. Bland-Altman Plots for Sleep Variables Obtained from the ASM and Sleepscan

Each plot represents the data from each participant. Mean values and differences between the devices (Sleepscan minus ASM) are shown on the x- and y-axis, respectively. The solid line and dotted line in each graph represent bias (mean difference between the devices) and the agreement limits (mean difference ± 1.96 × SD), respectively.

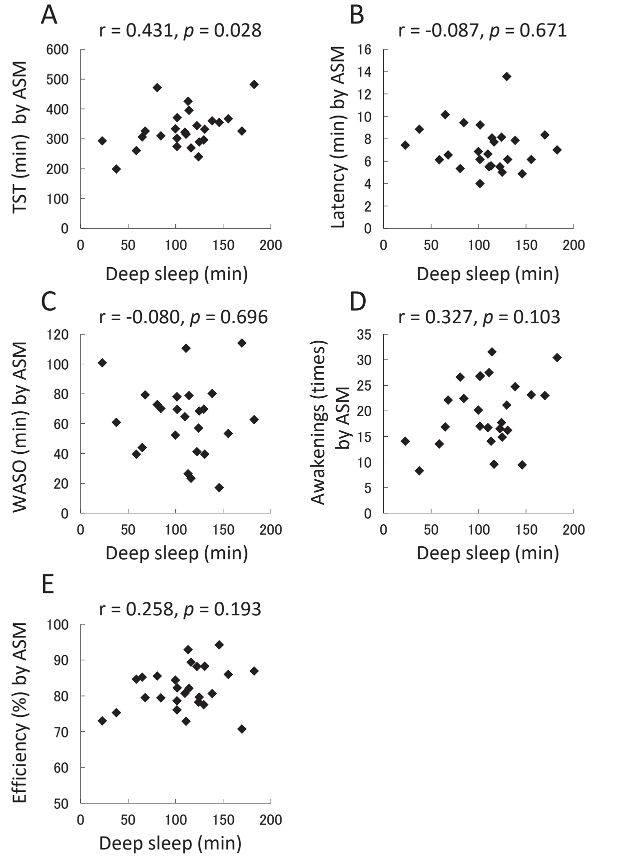

Fig. 5. Correlation between the Sleep Variables by ASM and Deep Sleep by Sleepscan

TST (A), sleep latency (B), WASO (C), number of awakenings (D), and sleep efficiency (E) by ASM and the total deep sleep duration by Sleepscan were plotted. Each plot represents the results of each participant.

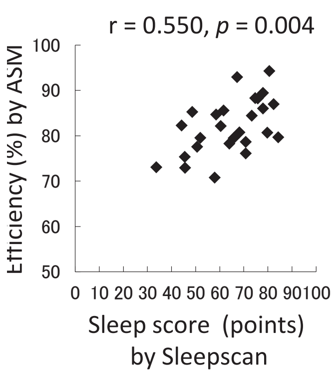

Fig. 4. Correlation between Sleep Efficiency by ASM and the Sleep Score by Sleepscan

Each plot represents sleep efficiency by ASM and the sleep score by the Sleepscan from each participant.

example, the participant in Fig. 1B might be awake but remain motionless, trying to fall asleep in the first 1 h after going to bed. The ASM estimated most of this period as sleep. Sleepscan may overcome this limitation to some extent by using the participant's respiration and heart rates as well as their body movement when estimating whether they are awake or asleep. Longer sleep latency by Sleepscan than the ASM suggests that Sleepscan can distinguish the motionless awake period from sleep. A previous study also reported longer sleep latency by Sleepscan than actigraphy,[15] and another study said that sleep latency by Sleepscan is comparable with that by PSG.[10] These studies and the present results suggest that Sleepscan can estimate sleep latency more accurately than actigraphy. On the other hand, Sleepscan detects shorter WASO than ASM. Previous studies reported that actigraphy is useful in estimating WASO,[16),] and Sleepscan detects shorter WASO than PSG.[10] These results suggest that Sleepscan fails to detect WASO correctly. Sleepscan might be better than actigraphy for analyzing sleep latency, but not for analyzing WASO. Since many sleep complaints are accompanied by difficulty falling asleep in all age groups,[1,20] accurate estimation of sleep latency is important. Sleepscan can, therefore, be an efficient tool for analyzing sleep of those people.

Next, the correlation between sleep efficiency by ASM and the sleep score by Sleepscan was analyzed. These variables are used as a representative index for comprehensive sleep quality in respective devices. Figure 4 shows a moderate correlation between these two variables (r = 0.550, $p < 0.05$). Although the correlation is not very strong, the sleep score can be used as an alternative measure of sleep efficiency by ASM.

Analysis of deep sleep is one of the advantages of Sleepscan over ASM. Figure 5 shows the correlation between deep sleep by Sleepscan and sleep variables by ASM. Total deep sleep duration by Sleepscan shows moderate correlation with TST (r = 0.431, $p < 0.05$) by ASM. The mechanism and importance of this correlation should be clarified by further study.

There is no other remarkable correlation between deep sleep and the other sleep variables, suggesting that deep sleep might represent some aspects of sleep quality that cannot be detected by other sleep variables such as sleep latency, WASO, and sleep efficiency. Sleep analysis with Sleepscan may be efficient in investigating the multifaceted function of sleep. Further study is necessary to clarify the significance of deep sleep variables for good sleep quality and health.

CONCLUSION

Sleepscan is a non-invasive mattress type sleep measuring device. It can analyze various sleep variables, including deep sleep. The sleep score by Sleepscan is comparable to the actigraphy sleep efficiency score. The sleep score by sleepscan can be used as an alternative index of comprehensive sleep quality. Deep sleep variables by Sleepscan may represent some aspects of sleep quality that are not detectable by actigraphy. Sleepscan can be a useful alternative tool for objective sleep analysis in daily life.

Conflict of interest The authors declare no conflict of interest.

REFERENCES

1) Doi Y. Prevalence and health impacts of sleep disorders in Japan. *Hoken Iryou Kagaku*, **61**, 3–10 (2012).
2) Cappuccio FP, Cooper D, D'Elia L, Strazzullo P, Miller MA. Sleep duration predicts cardiovascular outcomes: a systematic review and meta-analysis of prospective studies. *Eur. Heart J.*, **32**, 1484–1492 (2011).
3) Beihl DA, Liese AD, Haffner SM. Sleep duration as a risk factor for incident type 2 diabetes in a multiethnic cohort. *Ann. Epidemiol.*, **19**, 351–357 (2009).
4) Jansson-Fröjmark M, Lindblom K. A bidirectional relationship between anxiety and depression, and insomnia? A prospective study in the general population. *J. Psychosom. Res.*, **64**, 443–449 (2008).
5) Kushida CA, Litner MR, Morgenthaler T, Alessi CA, Bailey D, Coleman J Jr, Friedman L, Hishkowitz M, Kapen S, Kramer M, Lee-Chiong T, Loube DL, Owens J, Pancer JP, Wise M. Practice parameters for the indications for polysomnography and related procedures; an update for 2005. *Sleep*, **28**, 499–523 (2005).
6) Sadeh A, Hauri PJ, Kripke DF, Lavie P. The role of actigraphy in the evaluation of sleep disorders. *Sleep*, **18**, 288–302 (1995).
7) Sadeh A. The role and validity of actigraphy in sleep medicine: an update. *Sleep Med. Rev.*, **15**, 259–267 (2011).
8) Jean-Louis G, Kripke DF, Cole RJ, Assmus JD, Langer RD. Sleep detection with an accelerometer actigraph: comparisons with polysomnography. *Physiol. Behav.*, **72**, 21–28 (2001).
9) Noh T, Serizawa Y, Kimura T, Yamazaki K, Hayasaka Y, Itoh T, Izumi S, Sasaki T. The assessment of sleep stage utilizing body pressure fluctuation measured by water mat sensors. *J. Adv. Sci.*, **21**, 27–30 (2009).
10) Yamamoto M, Iga T, Shimizu M, Kohara S, Yoshii F, Urano T, Aoki T, Abe T. Mattogatasuiminkei no yuuyousei ni kansuru kentou (Evaluation of the usefulness of mat-type sleep monitor). *Sleep Med. Jap.*, **6**, 473–480 (2012).
11) Kasai K, Kobayashi H, Kawashima K. Measurement of nocturnal sleep state by a mattress-type sleep monitor in a nursing home. *Jap. J. Nurs. Art Sci.*, **14**, 195–199 (2015).
12) Cole RJ, Kripke DF, Gruen W, Mullaney DJ, Gillin JC. Automatic sleep/wake identification from wrist activity. *Sleep*, **15**, 461–469 (1992).
13) Yoshii F, Shimizu M, Kohara S, Yamamoto M, Iga T, Sasaki T, Honda Y, Yamaya C. Mattogatasuiminkei no kaihatsu to suimintensu wo motiita suiminjotai no hyoka (Development of mat-type sleep monitor and evaluation of sleep status by using sleep score). *Sleep Med. Jap.*, **6**, 361–365 (2012).
14) Acebo C, Sadeh A, Seifer R, Tzischinsky O, Wolfson AR, Hafer A, Carskadon MA. Estimating sleep patterns with activity monitoring in children and adolescents: how many nights are necessary for reliable measures? *Sleep*, **22**, 95–103 (1999).
15) Konishi M, Nakanishi J, Nishida K. The usefulness of mat-type sleeping monitor in elderly people's automatic sleep/wake identification judging – from comparison with a actigraph. *Bull. Ehime Prefer. Univ. Health Sci.*, **9**, 5–9 (2012).
16) Martin JL, Hakim AD. Wrist actigraphy. *Chest*, **139**, 1514–1527 (2011).
17) Paquet J, Kawinska A, Carrier J. Wake Detection capacity of actigraphy during sleep. *Sleep*, **30**, 1362–1369 (2007).
18) Kosmadopoulos A, Sargent C, Darwent D, Zhou X, Roach GD. Alternatives to polysomnography (PSG): a validation of wrist actigraphy and a partial-PSG system. *Behav. Res. Methods*, **46**, 1032–1041 (2014).
19) Marino M, Li Y, Rueschman MN, Winkelman JW, Ellenbogen JM, Solet JM, Durin H, Berkman LF, Buxton OM. Measuring sleep: Accuracy, sensitivity, and specificity of wrist actigraphy compared to polysomnography. *Sleep (Basel)*, **36**, 1747–1755 (2013).
20) Mishima K. Sleep and sleep disorders in the elderly. *Hoken Iryou Kagaku*, **64**, 27–32 (2015).